Theoretical Predictions for Upsilon Production at RHIC and LHC

And the Search for the Quark-Gluon Plasma

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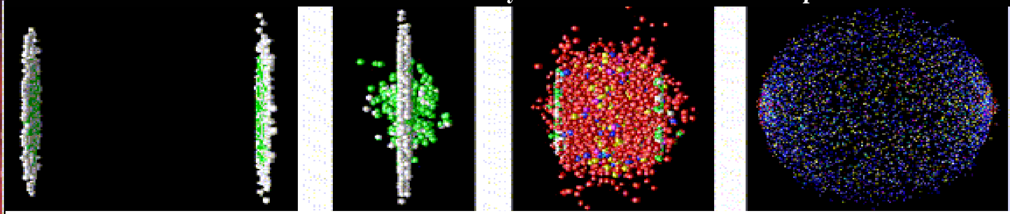
Project Goal: In this project we predict ϒ abundances at LHC and RHIC by taking into account both suppression **and** regeneration effects exclusively in the QGP

$$\Upsilon + g \Leftrightarrow b + \bar{b}$$

Evolution of Ultra-Relativistic Heavy Ion Collisions: *Fireball Expansion*



Lorentz-Contracted Nuclei | Hard Parton Collisions | QGP Phase | Hadron Gas Phase

Regeneration of ϒ in the QGP

Calculation for ϒ Equilibrium Abundances

[1] $N_\Upsilon^{eq}(T,\gamma_b) = 3\gamma_b^2 V_{FB}\int_0^\infty \frac{d^3p}{(2\pi)^3} f^\Upsilon(m_\Upsilon;T)$

f^Υ is the Maxwell-Boltzmann distribution function

- A fugacity factor (γ_b) is introduced to account for chemical off-equilibrium and is calculated by adjusting the total number of b-quark pairs in the system to the statistical bottom quark abundances:

[2] $N_{b\bar{b}} = \frac{1}{2}\gamma_b N_{op}\frac{I_1(\gamma_b N_{op})}{I_0(\gamma_b N_{op})}$

I_1/I_0 are modified Bessel functions needed for conservation of bottom quantum number in the canonical regime

•Eqn. [2] follows under the assumption that all bottom quarks are created in primordial NN collisions:

[3] $N_{b\bar{b}} = \frac{\sigma_{pp->b\bar{b}}}{\sigma_{pp}^{tot(inelastic)}} \times N_{collisions}$

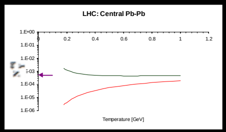
•We considered the statistical abundances in the QGP for the 2 extreme cases of b-quark masses:

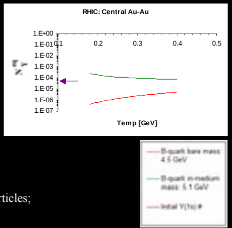
–bare mass ~ 4.5 GeV and

–in-medium mass ~ 5.1 GeV, derived from thermal correlation energies

[4] $N_{b,\bar{b}} = 6\,V_{FB}\int_0^\infty \frac{d^3p}{(2\pi)^3}[\exp(-\frac{\sqrt{m_b^2+p^2}}{T})]$

Sensitivity of Equilibrium #'s to B-quark Masses





- Equilibrium #'s diverge at low temps:

  $\Delta m = (2m_b) - m_\Upsilon$ (for free b-quarks)

- If $\Delta m > 0$, energetically favorable to form ϒ particles; larger equilibrium #:

- Note: Initial ϒ number is comparable to equilibrium numbers – Gain term is important!

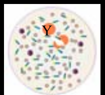
[5] $N_\Upsilon = \frac{\sigma_{pp->\Upsilon}}{\sigma_{pp}^{tot(inelastic)}} * N_{collisions} * S_{absorption}$

$S_{absorption}$ accounts for dissociation of pre-resonance ϒ particles

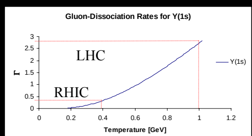
Dissociation of ϒ in the QGP

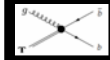
- ϒ particles travel through a dense parton medium (QGP) early in the collision
- Gluon-dissociation is the suppression mechanism used in our calculations for the ground state [ϒ(1s)]:

$$\Upsilon + g \Leftrightarrow b + \bar{b}$$



Upsilon break-up by energetic gluons in the QGP





Feynman Diagram of dissociation process

Rate Equation

'Used to comprehensively describe interplay of suppression & regeneration in the time evolution of ϒ abundances

$$\frac{dN_\Upsilon}{d\tau} = -\Gamma_\Upsilon[N_\Upsilon - N_\Upsilon^{eq}]$$

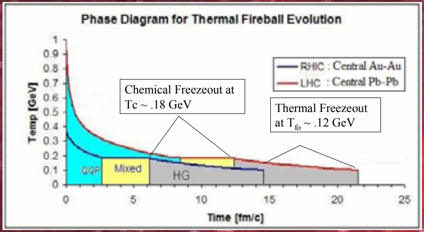
N_Υ = # of ϒ particles in the system at a given time, τ

Γ_Υ =dissociation rate as a function of temperature

$\Gamma_\Upsilon(T) = \tau_\Upsilon^{-1}(T)$ → Inverse lifetime of ϒ

N^{eq} = equilibrium ϒ abundances (gain term) Can be neglected if

$N_\Upsilon^{initial} >> N_\Upsilon^{eq}$



Volume/Time parameterization: Cylindrical Symmetry

$V_{FB}(\tau) = (z_0 + v_z\tau + \frac{1}{2}a_z\tau^2)\pi(r_0 + \frac{1}{2}a_\perp\tau^2)^2$

Volume/Temp: Entropy

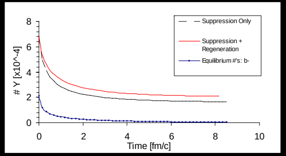
$V(T) = \frac{S_{Tot}}{s_{QGP(T)}}$ → Entropy density $s_{QGP} = d_{(Q+G)}\frac{4\pi^2}{90}T^3$

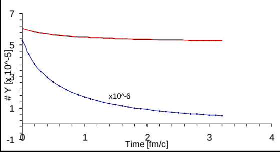
Rate Equation Results: Evolution of ϒ Abundances

LHC : Pb – Pb, $\sqrt{s}$ = 5500GeV

RHIC : Au - Au, $\sqrt{s}$ = 200 GeV

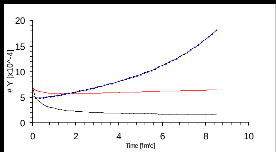
M_b = 4.5 GeV (bare mass)

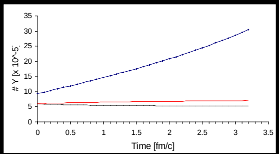




Suppression

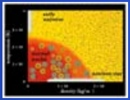
M_b = 5.1 GeV (in-medium mass)

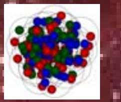




Regeneration!

Significance: Regeneration of ϒ has never been considered in previous production models





Conclusions

- Developed new model for ϒ production at LHC and RHIC
- ϒ abundances were calculated using kinetic rate equations to account for simultaneous suppression and regeneration effects in the QGP
- Resulting abundances show a strong sensitivity to the b-quark masses assumed in the system
- **Regeneration** dominates in the case of the in-medium b-quark mass: 5.1 GeV
- **Suppression** dominates for bare b-quark mass of 4.5 GeV

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